

MY-STAR: A Methodology and System For Tracing and Analyzing Requirements

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Abstract

This paper describes a methodology developed at the Jet Propulsion Laboratory (JPL), and designed for the process of requirements engineering and management. MY-STAR provides techniques for specifying, refining, allocating, baselining, sharing, changing, storing, and reporting on requirements and requirements metrics. In support of MY-STAR, the tool STAFR (System For Tracing and Analyzing Functional Requirements) has been prototyped by the Ground Systems Group (Software Product Assurance) as part of the process assurance support to four different projects within the Deep Space Network (DSN) at JPL. The results show that STAFR provides an effective means for capturing in one place requirements, while enabling refinement, analysis, traceability of test cases to requirements, and other trade-off artifacts associated with the specifications, prioritization, allocation and planning of requirements. It does so without the significant overhead typically associated with knowledge-based systems.

Introduction

Software requirements analysis in general is characterized by (1) identification of users needs, (2) documentation to describe the external behavior of the to-be-developed product and associated constraints to satisfy the users' expected needs, (3) analysis and validation of requirements, and (4) managing the evolution of users' needs and associated requirements.

More than often, requirements are fragmentary, address high-level functionalities, have some key requirements missing, contain ambiguous, inconsistent or contradictory constraints, and may not address the core needs of the customers.

Formal requirements-engineering has been a recognized and growing part of system engineering. Allocation of requirements, flowdown, and requirements tracing are part of this formal process.

The requirement engineering process begins with building a database. Next, the System Engineer (SE) may elect to drive a functional hierarchy and allocate requirements to functional areas (i.e., systems or subsystems). The SE is now in the position to establish a traceable requirement database, by associating requirements in a Parent/child relationship, assigning keywords and attributes. Attributes may include Source-of-requirement, Descriptive-text, and Priority.

Functional Allocation involves allocating DSN-network requirements (or level-0) at the root level to one or more functional areas such as facility(ies) or DSN-system(s) (or level-1). This process is repeated to the lower levels of the DSN system hierarchy. In performing this allocation, the SE will need to change the requirements (via additions, deletions, and/or corrections). For easier referencing, each requirement shall be uniquely labeled (manually or automatically). To ensure unicity of requirement labeling, the following rules apply.

A (level-0) network requirement must be labeled

NNN.n

where NNN is the acronym of the module or document, and n is a numerical identifier sequentially assigned to the requirement upon release (i.e., baselining).

A (level-1) system requirement must be labeled

SSS.n

where SSS is the acronym of the DSN system, and n is a numerical identifier sequentially assigned to the requirement upon release (i.e., baselining).

A (level-2) subsystem requirement must be labeled

sss.n

where sss is the acronym of the DSN subsystem, and n is a numerical identifier sequentially assigned to the requirement upon release (i.e., baselining).

By convention, every requirement statement will be so recognized by its "shall", and will be uniquely identified. There is a 1-to-1 relationship between the requirement identifier and the paragraph number associated with that requirement statement,

Flowdown consists of writing the requirements for the lower elements of the system or subsystem, in response to the allocation process.

When a requirement is a policy, constraint, or design goal, the SRE might choose to allocate it to one or more specific functional areas. Expansion is, however, not needed. Requirement statements that belong to this category can be carried forward and downward, but typically do not undergo acceptance testing. Proper annotation is recommended, to differentiate such requirements from those that must be subjected to formal acceptance testing.

When a network requirement is allocated to a given system (or subsystem), the system (or subsystem) must have at least one requirement that responds to the allocation. If the SRE decides that no expansion is needed, the parent requirement must then be re-stated in its entirety and with minimum editing change.

(This later step is critical to ensuring the rigor of requirement flowdown and the verifiability of its completeness.)

Similarly, when a system requirement is allocated to a given subsystem (or assembly), the subsystem (or assembly) must have at least one requirement that responds to the allocation.

Functional requirements must each have the following quality attributes:

- (a) complete (i.e., internally consistent and detailed enough for further analysis and cost estimating)
- (b) unambiguous (i.e., limited to a single interpretation of need)
- (c) feasible (i.e., implementable within reasonable or available resources)
- (d) testable (i.e., can be demonstrated, inspected, or refuted by a finite, cost effective process)
- (e) containing only one requirement statement and uniquely identified.

- (f) prioritized (i.e., assigned a priority level)
- (g) traceable (i.e., to a higher or lower requirement within a given hierarchy)

Traceability

Traceability involves among other things the answer to the following two questions:

1. Are all functions, structure, and constraints traced to requirements and vice versa?
2. Is each requirement stated in a manner that can be uniquely referenced in subordinate documents?

Traceability provides software developers with facilities to track the history of every feature of a system; the impact of a change to this feature on the system design, safety, cost and schedule. In essence traceability provides the means for software developers to prove to their customers or users that their requirements had been understood and that the delivered product meets their needs and satisfaction.

Requirements tracing consists of creating associations:

- (a) between a parent requirement and its child requirements;
- (b) between a set of requirements and one or more common requirement-attributes.

Once established, the requirements database is "open" (i.e., it can be manipulated by more than one vendor's tool to yield new associations, static or dynamic).

The major restriction on establishing a parent/child requirement relationship is that such a relationship must not violate the established functional hierarchy.

The SE must ensure that all system requirements have been responded-to in the lower-level specifications.

The Subsystem Engineer (SS1 E) must ensure that all subsystem requirements have been responded-to in the lower-level specifications.

STAFR

The System for Tracing and Analyzing Functional Requirements (STAFR) is a set of tools and procedures, which serve the purpose of storing the functional requirements generated by the Telecommunications and Data Acquisition (TDA/DSN) system/subsystem engineers into a database in such a way that: (a) they can be readily updated by the authors; (b) they can be traced up to their sources, and down to their lower-level components; (c) the Functional Requirements Document (FRD) database can support all phases of the system life-cycle, by relating the functional requirements to other types of requirements (e.g., acceptance criteria), to planning information (e.g., phase/build allocation), or to status-information (e.g., test-status).

STAFR has been developed using dBase 1 V as the database tool and WordPerfect as the reporting tool, within a DOS-based, IBM/PC-compatible environment. These were chosen for the pilot as they represent the most commonly used tools among TDA/DSN system engineers (who are PC users) and will, therefore, require minimal training.

STAFR provides the SE with the mechanisms to build such a requirements database. STAFR provides at least two ways of entering requirements into the database: a manual but dynamic (i.e., interactive) one, and an automatic one.

Output

A sample output of MY-STAR methodology and STAFR tool is shown in Tables 1-6 and Figure 1. Shown in Table 1 is the functional requirements baseline with PR = priority (A, B, C); PHASE = phase or build, and ALLOCATION = allocation to a particular assembly or subassembly.

Table 2 shows the functional requirements test plan matrix, where DMC/MT = terminal type where test is to be carried, LOCATION = location of test as laboratory, site, etc., DOCUMENT = test document, and ASSIGN TO = name of person responsible to provide test procedure.

Table 3 shows the functional requirement test traceability matrix, where

PRTY = priority

TEST METHOD = method of verifying/validating the requirements:

A: Analysis

I: Inspection

T: Testing

"J"] {S/CASE} = is the set of tests and cases within this set

Table 4 shows the requirements classification matrix, and Table 5 shows the requirements changes. Table 6 shows the functions] requirements that are to be deferred, with

PRTY = priority

S' I' A' = partially deferred (P), or
whole deferred (N)

and IMPACT/COMMENTS = gives the deferred until date.

Figure 1 shows a simple metric depicting the number of requirements allocated to the total number of requirements.

Conclusion

Traceability is increasingly becoming one of the most important tenets of Total Quality Management (TQM). Traceability helps developers to produce the right product right, with less defects, rework or scrap; and also insures customers or users to receive products that meet their needs and satisfaction. The overall benefits to both developers and users include high quality product within, perceived budget and schedule.

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**Table L Antenna Controller Replacement (ACR) Task
Functional Requirements Baseline**

REQ. ID	FUNCTIONAL REQUIREMENT	PR	PHASE	ALLOCATION	COMMENTS
3.5.3.1.14	Periodic Reports. The ACG shall generate periodic reports to provide antenna status and position for users who need this data.	A	1	APC	
3.5.3.1.14.1	These reports shall be in accordance with Reference Document (7), 820-16.	A	1	APC	
3.5.3.1.15	Graphic Displays. The ACG shall generate an overall graphic display for the DMC which shows synoptic high-level status and configuration of the antenna and each of its major assemblies.	A	1	APC	
3.5.3.1.16	Detailed Displays. The ACG shall generate displays showing detailed monitor and control, performance, and status information.	A	1	APC	
3.5.3.2.27	Fault Isolation. In the event of a malfunction, and when so directed, the ACG shall locate the fault to the lowest replaceable module and report this to the DMC operator.	A	1	APC	
3.5.3.1.17.1	Alternate Operating Was. If there is a built-in alternative capability, this shall be suggested to the DMC operator.	A	1	APC	
3.5.3.7.18	Data Storage. The ACG shall store all configuration and prediction data in non-volatile memory and provide the capability to automatically restart after a power outage up to the point of actual antenna motion.	A	1	APC	
3.5.3.1.19	Shutdown. With a single command, the ACG shall provide the capability to prepare the antenna for power shutdown for an indefinite time and perform that shutdown.	A	1	APC	
3.5.3.1.20	Time and Timing Data. The ACG shall accept time and timing signals in accordance with Reference Document (6), 8=17.	A	1	APC	
3.5.4.1A	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (1) Spacecraft, using predicts as defined in Reference Document (7), 820-16, TRK 2-205 ,	A	1	APC	
3.5.4.1.9	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (2) Local, using predicts as defined by multiple points of topocentric hour angle/declination or azimuth/elevation, range, day of year, and time. Up to 1000 data points shall be accepted, stored, and utilized.	A	1	APC	
3.5.4.1.C	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (3) Sidereal, using predicts defined by geocentric right ascension, declination, range, day of year, and time. Up to 1000 sets shall be accepted, stored, and utilized.	A	1	APC	

**Table 2. Antenna Controller Replacement (ACR) Task
Functional Requirements Test Strategy**

REQ. ID	FUNCTIONAL REQUIREMENT	DMC/MT	LOCATION	DOCUMENT	ASSIGN TO
3.5.3.1.16	Detailed Displays. The ACG[APC] shall generate displays showing detailed monitor and control, performance, and status information.	B	L, c	STP	Berg
3.5.3.1.17	Fault Isolation. In the event of a malfunction, and when so directed, the ACG[APC] shall locate the fault to the lowest replaceable module and report this to the DMC operator.	D	c, s	STP, SITP	Berg, Schneider
3.5.3.1.171	Alternate Operating Modes. If there is a built-in alternative capability, this shall be suggested to the DMC operator.	D	c, s	STP	Berg/Ahlstrom
3.5.3.1.18	Data Storage. The ACG[APC]s shall store all configuration and prediction data in non-volatile memory and provide the capability to automatically restart after a power outage up to the point of actual antenna motion.	B	L, C	STP	Berg
3.5.3.1.19	Shutdown. With a single command, the ACG[APC] shall provide the capability to prepare the antenna for power shutdown for an indefinite time and perform that shutdown.	E	S	STP, SITP	Berg, Schneider
3.5.3.1.20	Time and Timing Data. The ACG[APC] shall accept time and timing signals in accordance with Reference Document (6), 820-17.	H/W	L, c	ATP, STP	Ahlstrom, Berg
3.5.4.1.A	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (1) Spacecraft, using o & a as defined in Reference Document (7), 820-16, TRK 2-205	M	L, C, S	STP, SITP	Berg, Schneider
3.5.4.1.B	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (2) Local [mode tracking shall use an azimuth/elevation or hour-angle/declination predict to point the antenna at a fixed point in the sky]. Up to 1000 [predict] points shall be accepted, stored, and utilized at specified times.	M	L, C, S	STP, SITP	Berg, Schneider
3.5.4.1.C	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (3) sidereal, using predicts defined by geocentric right ascension, declination. Up to 1000 [sidereal points] shall be accepted, stored, and utilized at specified times.	M	L, C, S	STP, SITP	Berg, Schneider
3.5.4.1.D	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (4) Planetary, using predicts defined by three groups of geocentric right ascension, declination, range, day of year, and time, from 0.1 hour to 48 hours apart to define a planetary trajectory. Up to 255 groups of these predicts shall be accepted, stored, and utilized.	M	L, C, S	STP, SITP	Berg, Schneider
3.5.4.1.E	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (5) Cross-support, using geocentric improved inter-range vectors (IRV), as defined in Reference Document (10), 820-13, TRK 2-17.	M	L, C, S	STP, SITP	Berg, Schneider

**Table 3. Antenna Controller Replacement (ACR) Task
Functional Requirements Test Traceability Matrix**

REQ. ID	PERFORMANCE REQUIREMENTS	PRTY	TEST MTHD	TEST/CASE	DOCUMENT	ASSIGN TO	COMMENTS
3.3.2.1	Surface Accuracy. The antenna shall provide a combined primary, secondary, and BWG reflector surface RSS of ≤ 0.024 inches at the rigging angle, nominally 45 degrees, with no wind, and a combined RSS of ≤ 0.0265 in any elevation position from 10 to 80 degrees with no wind.	A	I	4.1	SITP	Rochblatt/Yung	
3.3.2.2	Noise Contribution. The antenna shall be designed so that the zenith noise contribution generated by the antenna at either S-, X-, or Ka-band due to all spillovers, leakage, and scattering IIR losses, including any dichroic reflector, is as follows: S-band 10K X-band 7K Ka-band 13K	A	I	4.3	SITP	Britcliffe	
3.3.2.3	Efficiency. The 34-m BWG antenna shall meet the following efficiency requirements, with the understanding that other subsystem equipment may be required to perform these measurements. The following efficiencies include all antenna elements, except the microwave feed "R" losses and voltage-standing wave ratio (VSWR): Elevation/Band-GHz 2.3 8.4 34 10° 81% 80% 44% 45° 82% 83% 53% 80° 81% 79% 44%	A	I	4.4	SITP	Britcliffe	
3.3.3.1	Path Length Stability. The antenna shall be designed to provide a one-way path length stability to limit the uncertainty of the antenna contribution to the phase residuals such that the Allan deviation of the antenna contribution to the signal is less than 2.7×10^{-15} for sample intervals of 1,000 to 10,000 seconds under the following conditions: Wind - no higher than 10 mph Weather - clear, cloudless conditions Gravity - from 20° to 88° antenna elevation angles		I	4.5	SITP	Britcliffe/Yung	Unknown at this time/ test requires completed antenna system

Table 4. Antenna Controller Replacement (ACR) Task
Functional Requirements Clarification

R/O. ID	ORIGINAL REQUIREMENT	CLARIFICATION
3.3.4.1	Rate. The minimum slew rate in each axis shall be 0.8 deg/sec. "e"	Slew Rate. The slew rate in each axis shall be 0.8 deg/sec as a minimum.
3.3.4.2	Tracking Rate. The tracking rate in each axis shall be from 0.0001 to ≥ 0.4 deg/sec.	Tracking Rate. The range of tracking rate shall be between 0.0001 to 0.4 deg/sec, as a minimum.
3.3.4.3	Acceleration. The acceleration in each axis shall be ≥ 0.4 deg/sec**2 up to a rate of 0.4 deg/sec.	Acceleration. The acceleration in each axis shall be 0.4 deg/sec**2, or greater, up to a rate of 0.4 deg/sec.
3.3.4.4	Deceleration. The deceleration (braking) in each axis shall be ≥ 5.0 deg/sec.	Deceleration. The deceleration in each axis shall be 5.0 deg/sec**2, or greater.
3.3.4.6.2	Motion Limits. The antenna shall be capable of moving to any position within the following limits. Elevation operational limits shall be ≤ 6 deg and ≥ 89.5 deg.	The range of elevation motion shall be between 6 and 89.5 deg, as a minimum.
3.3.6	The subreflector shall be mounted on a positioner which allows it to be moved in each axis (axial [y, X, Y] to optimize the focusing of the optics.	The subreflector shall be mounted on a positioner which allows it to be moved in each axis (axially, X, Y, Z) to optimize the focusing of the optics.
3.3.6. f.	Accuracy. The positioner shall be able to locate the subreflector within ± 0.010 inches of the assigned position relative to the quadripod center for each of the three axes.	Accuracy. The positioner shall be able to locate the subreflector within ± 0.010 inches of the assigned position relative to the quadripod center for each of the three two axes.
3.5.2.3	Antenna Pointing Control Function. The antenna pointing control function shall perform coordinate conversions, calculation of offsets to compensate for systematic and refraction errors, storage of system error tables and constants, convert predicted sky positions to antenna pointing positions, and supply these to the antenna servo control.	Antenna Pointing Control Function. The antenna pointing control function shall perform coordinate conversions, calculation of offsets to compensate for systematic and refraction errors, storage of systematic error tables and constants, convert predicted sky positions to antenna pointing positions, and supply these to the antenna servo control.
3.5.2.4	Antenna Servo Control Function. The antenna servo control function shall perform all functions associated with pointing the antenna at the target. This includes accepting position commands, comparing the actual antenna position with the commanded position, and issuing drive commands to the servos to maintain the antenna pointed at the commanded position.	This function shall close the position loops for the antenna axes. It shall issue rate commands to the antenna drives.
3.5.2.5	Subreflector Control Function. The subreflector control shall determine the antenna position, determine the optimum subreflector position, compare the actual position with the optimum value, and issue move commands to the subreflector drives.	Similar to the Antenna Servo Control Function, this function shall close the position loops for the subreflector axes. It shall issue rate commands to the subreflector drives.
3.5.2.5.1	In addition, the subreflector controller shall control the feed selection mechanisms on the 70-m and 34-m BWG antennas.	No Change

**Table 5. Antenna Controller Replacement (ACR) Task
Functional Requirements Changes**

REQ. ID	ORIGINAL REQUIREMENT (per 824-24)	UPDATED REQUIREMENT
3.5.2.3	Antenna Pointing Control Function. The antenna pointing control function shall perform coordinate conversions, calculation of offsets to compensate for systematic and refraction errors, storage of system error tables and constants, convert predicted sky positions to antenna pointing positions, and supply these to the antenna servo control.	Antenna Pointing Control Function. The antenna pointing control function shall perform coordinate conversions, calculation of offsets to compensate for systematic and refraction errors, storage of system[atic] error tables and constants, convert predicted sky positions to antenna pointing positions, and supply these to the antenna servo control.
3.5.2.4	Antenna Servo Control Function. The antenna servo control function shall perform all functions associated with pointing the antenna at the target. This includes accepting position commands, comparing the actual antenna position with the commanded position, and issuing drive commands to the servos to maintain the antenna pointed at the commanded position.	Antenna Servo Control Function. The antenna servo control function shall perform all functions associated with pointing the antenna at the target. [This function shall close the position loops for the antenna axes. It shall issue rate commands to the antenna drives.]
3.5.2.5	Subreflector Control Function. The subreflector control shall determine the antenna position, determine the optimum subreflector position, compare the actual position with the optimum value, and issue move commands to the subreflector drives.	Subreflector Control Function. [Similar to the Antenna Servo Control Function, this function shall close the position loops for the subreflector axes. It shall issue rate commands to the subreflector drives.]
3.5.2.5.1	In addition, the subreflector controller shall control the feed selection mechanism on the 70-m and 34-m BWG antenna.	3.5.2.5.1 In addition, the subreflector controller function shall control the feed selection mechanism on the 70-m.
		3.5.2.5.2 The Feed Control function shall also control the feed mirror mechanism on the 34-m BWG antenna.
3.5.4.1.B	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (2) Local, using predicts as defined by multiple points of topocentric hour angle/declination or azimuth/elevation, range, day of year, and time. Up to 1000 data points shall be accepted, stored, and utilized.	Tracking Modes. The antenna shall follow the predicts provided in one of the formats listed below: (2) Local [mode tracking shall use an azimuth/elevation or hour-angle/declination predict to point the antenna at a fixed point in the sky]. Up to 1000 [predict] points shall be accepted, stored, and utilized at specified times.

Table 6. Antenna Controller Replacement (ACR) Task
Functional Requirements To Be Deferred

FUNCTION	IMPLEMENTED BY 9/95.	LOCAL LOG WILL CONTAIN 1 DAY WORTH OF DATA.
3.5.2.8	removable record of important antenna parameters for problem analysis or to provide additional information to special users regarding antenna performance.	Deferred until 9/95.
	(Maintenance Terminal) shall provide data at the following defined sample rates, which (as a minimum) contain (1) 1/1 second: Encoder readouts, including Master Equatorial (M/E) readouts on the 70-m antennas in Az-EI and Ha-Dec subreflector position readouts, and status	Data to special user port, deferred until 9/95.
	(Maintenance Terminal) shall be provided data at the following defined sample rates, which (as a minimum) contain (2) 1/5 seconds: Predicted angles and all corrections and offsets in Az-EI and Ha-Dec for the antenna and the M/E. Predicted and actual positions and corrections in X, Y, and Z for the subreflector.	Data to special user port, deferred until 9/95.
3.5.3.	(Maintenance Terminal) shall be provided data at the following defined sample rates, which (as a minimum) contain (3) 1/30 seconds: Tracking mode and status, autocollimator in use, and status (70-m); all voltages, currents, pressures flows, temperatures, and levels.	Data to special user port, deferred until 9/95.
	(Maintenance Terminal) shall be provided data at the following defined sample rates, which (as a minimum) contain (4) 1/60 seconds: Weather data.	Data to special user port, deferred until 9/95.
	(Maintenance Terminal) shall be provided data at the following defined sample rates, which (as a minimum) contain (5) As they occur: All status, event, warning, and alarm notices.	Data to special user port, deferred until 9/95.
3.5.3	removable media in the control building) all parameters which could be required to enable reconstruction of failures, pointing problems, etc.	Deferred until 9/95.

Figure 1. Antenna Controller Replacement (ACR) Task
Functional Requirements Allocation Profile

